Introduction to Engineering Seismology
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Lecture No-32
Recapitulation - 4

So Vanakkam, so we are being seeing the recapping of all our basic understanding of the earthquake. So last class we have seen the different type of earthquake sources particularly fault and fault type and also we have seen the different type of earthquakes, so and depends upon the depth location where it occurs and what type of energy it released. So basically, the tectonic earthquakes are the major concern for the human being.

So where, we need to really understand. So we also seen that this earthquake actually causes here are occur or to where the fault is basically a weak zone or fracture place. So when the earthquakes are occurring basically what happens the weak zone fracture and the breaks. So during that breaks actually there is a jagged irregular progress of rupturing this two places. Even the same rock it breaks and rupture that rupturing basically create a seismic waves.

That create a seismic wave in the form of vibration, the vibration basically is a seismic waves. So this vibration so once it is originate you try to propagate all other direction uniformly.

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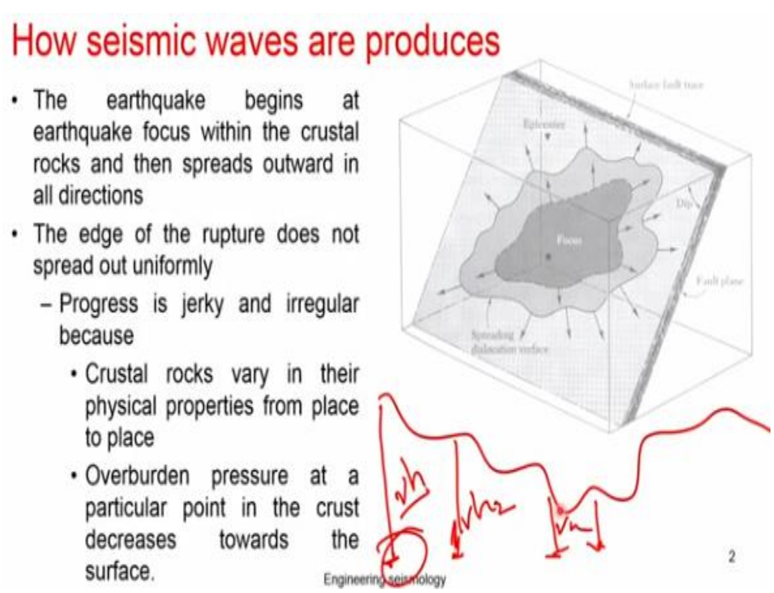

Where it occurs starting point actually is called as a focus, then it try to propagate around the; that focus point, but as we have seen that this has occurring in the rock. So there may be a different type of rock in the places. So that means the propagation of these waves, vibrations or waves it depends upon the material in the region. If there is the material is weak, the rupture will propagate very fast.

The material is strong it may not propagate it will stop. So we also seen the asperities, barriers during the; this discussion in the original class, but now I am not talking about in detail that. So the barriers is basically the stronger portion of the rock which is stop here propagation of the wave. So the asperities is the like it is a the propagation patches, whatever happening is asperities you can refer the old notes for the same basically are all the class discussion.

So apart from the material of the rock, the another factor, which controls or stops this propagation is actually the overburden pressure at that particular location. As we have seen that earth surface is very rich all those things. So the each location, what is the pressure we are expecting is the function of unit weight and the thickness of the material that is called as a overburden pressure.

This will change I am talking into very simple term but Civil engineers may understand this detail if those who are studied B.tech and Civil and all. So this overburden pressure will change differently at a different place. These also contribute to the stopping up this wave propagation. So basically if the overburden pressure is high it will stop the rupture phenomena, it is a low it will allow to propagate.

So depends over the rock properties under overburden pressure will be decide, what is the, your so the rupture direction, the rupture area all those things will be decided by these two major factors. So when these waves are travelling when the vibrations are travelling in the form of waves;

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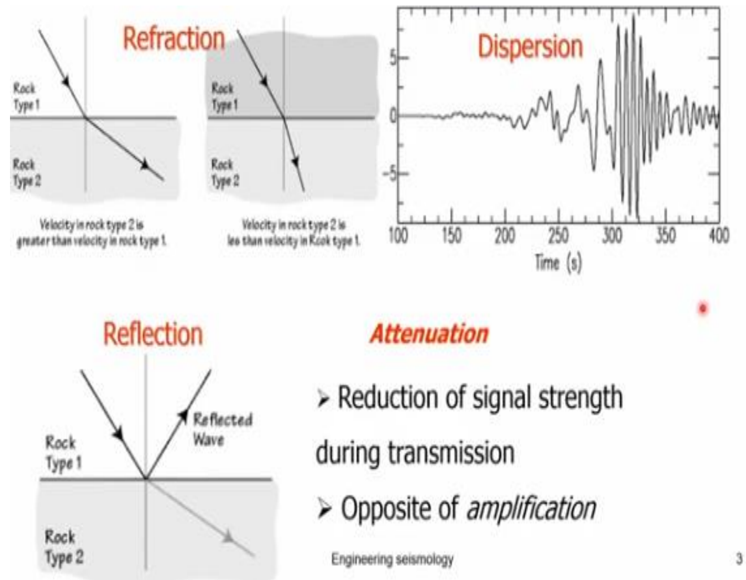

So the wave propagation occurs in the 3-4 major category, so what is that Reflection, Refraction and then the Dispersion and Attenuation. So what is the Reflection? Reflection as we are seen may be in the school physics like reflection of the light wave. Here also same instead of light you get a seismic wave. So the seismic wave travels from one medium because is its travels on the rock when it originate.

So one property at the rock when there is a change in the another property of the rock like a type 1 rock and type 2 rock, so then the part of the wave get reflected part of the wave get refracted. So this is a reflected wave and refracted wave, with this kind of phenomena is called as a reflection of the wave. So for example the waves the seismic wave so created by the earthquake travels down the earth.

As you see in that, the earth has a crust mantle and the inner core, outer core. So when it crusts to the mantle when it goes because of the change in the property of the rock the portion of the wave reflected portion of the wave refracted, that is what is the refraction is does. So similarly refraction so this portion wave which passes through one layer to other layer depends upon the type of the material.

For example, the velocity of the rock type 2 is greater than the velocity of the rock you can get this kind of refraction. So when the type of the rock 2 is less than the type 1 then you can get this kind of refraction. So these are all will give you what type of seismic wave you are recorded and what material it passed so that is the understanding will help you this kind of understanding of wave propagation.

We also seen dispersion the dispersion is basically separation of the wave. So some materials which separate the waves are it makes vibrate several times the depends upon the property. So that kind of things are explained in the dispersion. So the attenuation is some material will modify the wave amplitude, wave character will be modified so the Attenuation is basically reduced the wave amplitude is called as Attenuation.

Increase the wave signal strength or wave amplitude is called as amplification. So more or less the 4 major phenomena which occurs during the wave propagation refraction, reflection dispersion and the attenuation or amplification. So these are the 4 major phenomena it occurs.

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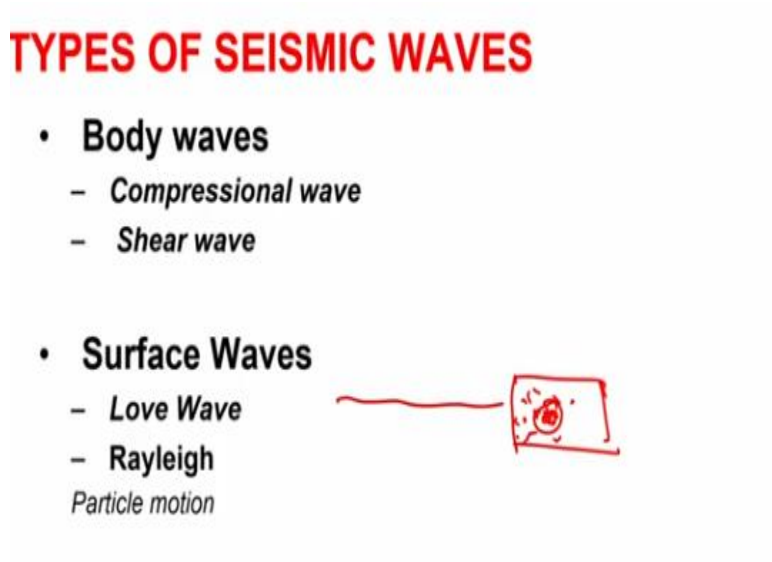

So this occurs with respect to the waves it travels, so the seismic waves even though we call it as a whatever vibration produced wave as called as all of them as a seismic wave, this waves are categorized 2 types depends upon the how it travels and how the medium respond to that travel. So there are 2 types of wave one is the body wave another one is a surface wave. So body wave basically travels body of the earth.

So that means the deep earthquake can cause a body wave traveling. So the surface wave travels on the surface of the earth. So even though this is a very simple explanation body and surface with respect to the which part of the medium it travels but precisely to express scientists taken a reference as a particle motion in the particular body. For example so this is the wave which travels then you will encounter a medium or a rock.

So this is a any medium or rocks assemblers of several particle. How this individual particle respond to a wave, then based on this particle moment that try to define here wave type. So the body wave has two major category one of them is Compressional wave another one is a Shear wave. The surface wave has two category love wave and the Rayleigh wave. So the compressional shear wave basically indicate a particle behavior that means particle is compressed particle is sheared.

The surface wave basically Love and Rayleigh waves named based on the scientist who invented that wave Love and Rayleigh at the person we invented that wave. So let us see how the compressional wave travels.

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So you can see here this medium very clearly the waves are created by the rupturing then the waves are travelling you take this particle as a reference you can see that during this wave this basically compress and elongate. So the particle compress and the elongate direction of the propagation of the wave that wave is called as a compressional wave, so or primary wave is called as a P wave. So this is the typical animation source that the wave propagation occurring on the P and;

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So the other portion so where the earthquakes are occurring waves are travelling. So the particles are basically most perpendicular direction of the wave you can clearly watch this particle you can see here. So this moves basically perpendicular to the direction of the wave. So this kind of wave, particle motions are perpendicular to the direction of the wave propagation, this is called as a S wave. So it is basically happens create a shear between the medium and particle or particle two particle that is called the shear wave or S wave.

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So then the portion of the wave in travels the particle basically rotates. So the particles are rotating with respect to the direction of the wave propagation that wave is called as a Rayleigh wave. The Rayleigh is a person who invented this wave. So since the rotations involved where the free body also come into picture, the rotation is major at the surface of the system and low at the bottom of the system.

You can see very clearly how the rotation take place you can see. So basically the larger rotation happens here and then less rotation happens here. So this is a unique character where the rotation happens but rotation also with respect to the depth it happens. So this is the surface wave but its a Rayleigh type of surface wave travels on the surface of the earth.

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So the another one is a love wave So Love wave is basically movement of the snake you can quote. So where the particles are basically perpendicularly moving with respect to the wave propagation, but not vertical it is horizontal. You can see that it is horizontally perpendicularly moving, you can see that movement again major at a surface and then reduces with the depth you can see this is how the particle.

You can see the each grid how the grid movement occurs on top and bottom, so this is a love wave. So basically, the Love wave is created, so invented by the scientists Love which created other surface of the earth during the earthquake or any vibration travel. So this 4 major category of the wave, its wave characters are very important in the engineering seismology.

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Wave Character

Wave Type	Particle Motion	Typical Velocity	Other Characteristics
P, **Compressional**, Primary, Longitudinal	Alternating compressions same direction as the wave is propagating	V_P ~ 5 – 7 km/s in typical Earth's crust; ~1.5 km/s in water; ~0.3 km/s in air.	Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves.
S, **Shear**, Secondary, Transverse	Alternating transverse motions, particle motion is in vertical or horizontal planes.	V_S ~ 3 – 4 km/s in typical Earth's crust;	S-waves do not travel through fluids, S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.

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So let see what are these waves as a characters. So the P wave, compressional wave, primary wave and longitudinal wave. So actually alternating the compression the same direction as the wave propagating how the particles are basically compressed and dilate and which goes like the VP is equal to so much it travels with the speed of 5 to 7 kilometer per second so in the solid medium and the 1.5 kilometer per second in the water and 0.3 kilometer per second in the air.

This is a typical velocity you can expect. So this velocity may vary 5 to 7, but it may be 5.5, 6.9 depends upon the location. So generally smaller and the higher frequency than the S wave or surface wave, P wave is liquid or gas or pressure waves including the sound waves. So whatever I am speaking the sound which creates travel in the air, know those kind of waves are called as a P wave.

The shear wave or secondary wave so the alternating transfers motion or particle motion in a vertical or horizontal plane. So this as a velocity range of 3 to 4 kilometer in the typical earth crust and the S wave do not travel through fluid. S wave travel slower than the P wave in a solid therefore arrives after the P wave, here you can see that S and a P wave. So the P wave velocities are higher, that means it comes very fast S wave comes next.

Second the P wave travel on water and S wave does not travel on water that is the second. Third so you can also see that the material property which we discussed during the wave propagation.

So here the P wave is controlled by the constrained modulus and density. So the S wave controlled by the shear modular density. So if you want to get a VP and VS relation, basically you there is a relation derived with respect to so the density Poisson ratio and a modulus. So you can convert one wave to other wave by knowing the, this kind of properties.

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Wave Type (and names)	Particle Motion	Typical Velocity	Other Characteristics
L, **Love**, Surface waves, Long waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface.	V_L ~ 2.0 - 4.4 km/s in the Earth depending on frequency, faster than the Rayleigh waves.	Decrease in amplitude with depth. dispersive, velocity is dependent on frequency, low frequencies - propagating at higher velocity. Lower frequencies penetrating to greater depth.
R, **Rayleigh**, Surface waves, Long waves, Ground roll	Motion is both in the direction of propagation and perpendicular	V_R ~ 2.0 - 4.2 km/s in the Earth waves.	Dispersive, amplitudes decrease with depth, Appearance like water waves. Depth of penetration dependent on frequency, lower frequencies penetrating to greater depth.

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So the other wave basically is the love wave, a surface wave, long waves. So the transverse horizontal motion perpendicular to the direction of the propagation and generally parallel to the earth surface which as a velocity range of 2 to 4.4 kilometer in the earth depending upon the frequency faster than the Rayleigh wave. So the Love wave comes first, so it is a faster than the Rayleigh wave.

So but if the velocity also depends upon the frequency content of the wave, that things you note previous two actually not that much depend upon the frequency content. Decrease in amplitude with the depth, so dispersive velocity is depend upon the frequency low frequency propagate higher velocity so lower frequency penetrating to the greater depth. So the Rayleigh waves, surface wave, long waves or ground roll.

Motion is both in direction of the propagation and the perpendicular where it rotates, so the velocity ranges 2 to 4.2 kilometer in the earth waves dispersive amplitude decrease with the depth appearance like a water waves depth the penetrate depends upon the frequency lower frequency penetrate to a greater depth. So if you go to the water body next time you throw your stone when you throw a stone so you will get a wave, in the circular wave the waves are traveling like this, now that waves are basically Rayleigh wave.

So that kind of waves basically water wave sound, so Love waves are basically snake moment that is a typical example so all these animations the way we explanation animations simple experiment are available in the YouTube. So you can actually browse it and get exposed to more the content how it travels, so even though the theory assumes like this homogenous heterogeneity medium and infinite depth on a semi-infinite and all.

But we do not want to basically to much explain on that which is not record of our the introduction class kind of things, so this is about the wave character this wave property are very important to interpret here seismic data recorded at a particular place. So if you have the seismic record, you should know what type of wave you are recorded. So that this wave property also defines the earth interior.

So people are recorded this waves at different places and then try to understand how the particular place.

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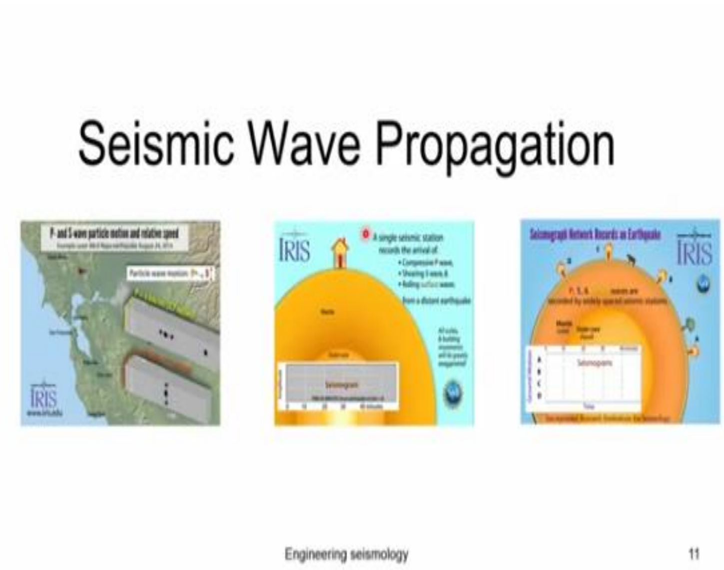

What type of wave you received by the wave propagation theory based on the wave propagation theory only. So we have seen some animation basically.

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You can see this animation so the earthquake originate at one place and then it moves at a different place you can see what type of wave and when it arrives, for example this is the origin earthquake is originated. So then it moves you can see the what; S wave, P wave when it travels P wave, when the S wave and how the your house or a typical house get disturbed or object in the surface disturbed.

So you can also see the amplitude with respect to different position, so this is the, so when you when you are seeing that the S waves are not traveling the interior that means some location you cannot get your record of S wave.

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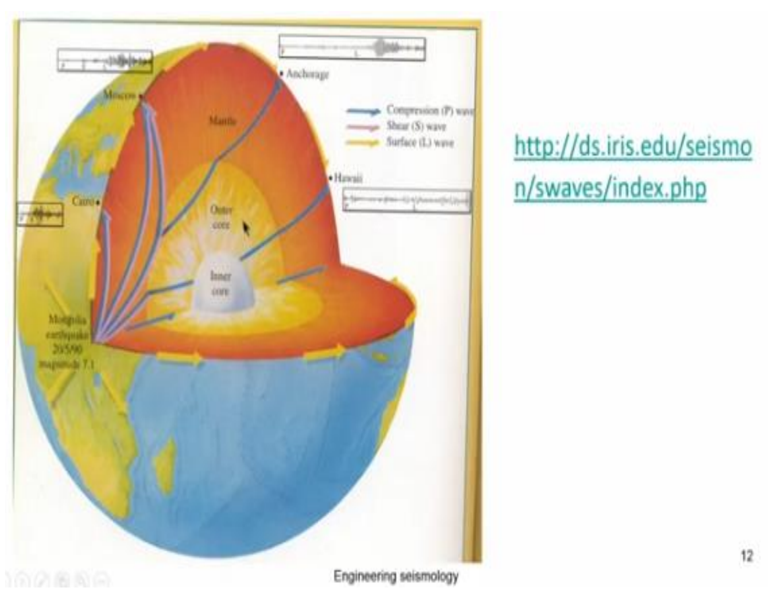

Well so those locations where you are not able to receive a particular wave that depends upon the your origin of the wave and position of where you are looking at, for example in this figure the earthquakes are occurring here, so you try to have the earthquake recording at a several place of the world. If you see this very clearly you can see basically this position, this position this position, this position.

The waves are travelling all around direction, but at particular location you may not receive particular wave depends upon the wave character. Per year, you may not receive a S wave as the interior of the outer core of the earth is basically even liquid. Liquid means not like water it is a relatively comparatively density of this material mantle on the outer core are different which is similar kind of solid very thick liquid kind of thing where it does not travel. So this decides particular zone or area do not have particular wave type.

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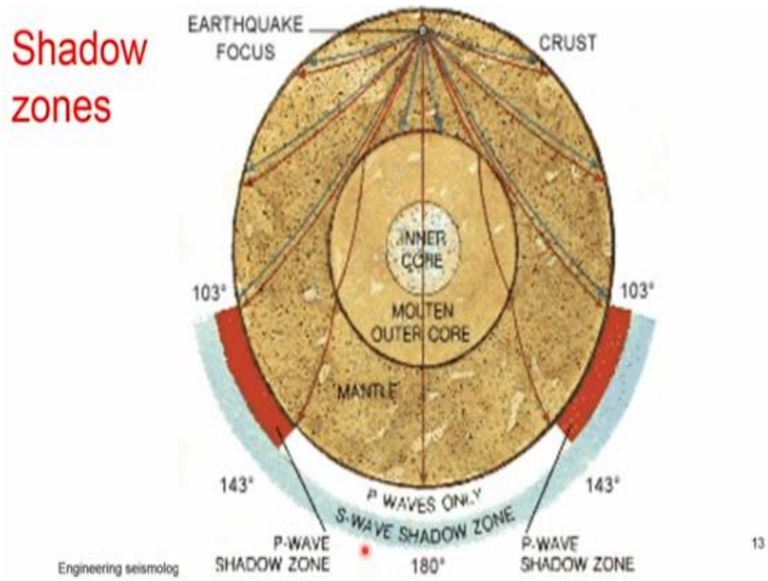

So then that defines a shadow zone. So if this is the place you see the earthquake is origin, so then it travels all along the direction scientists observe that the 103 degree from this middle and 140 degree so this portion you will not receive here a P wave because of the refraction. So refraction and the reflection you get you will not receive the P wave one this as well as the, this particular zone is called as a P wave shadow zone.

Similarly you will not receive the S wave from 103 to 103 this entire location that location is called as a S wave shadow zone. So when it heats the waves are transferred into different type of the waves.

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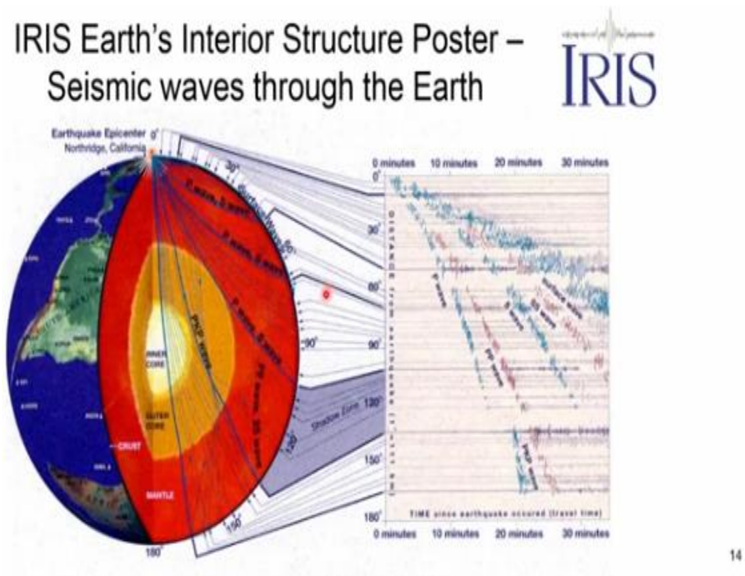

So like you can see here this is the typical earthquake recorded continuously at different places are the simulated this record at different places you can see that, so some places the P wave record some place the combination of P wave and S wave record someplace only S wave record some place only P wave record. So this is like the waves get transformed P wave get PP wave P and S wave, S wave get SS wave.

S wave and SP wave something like that the waves are get transferred into different portion, so depends upon the where you expect you are record where the wave origin you can get a particular type of wave or you will we do not get a particular type of wave.

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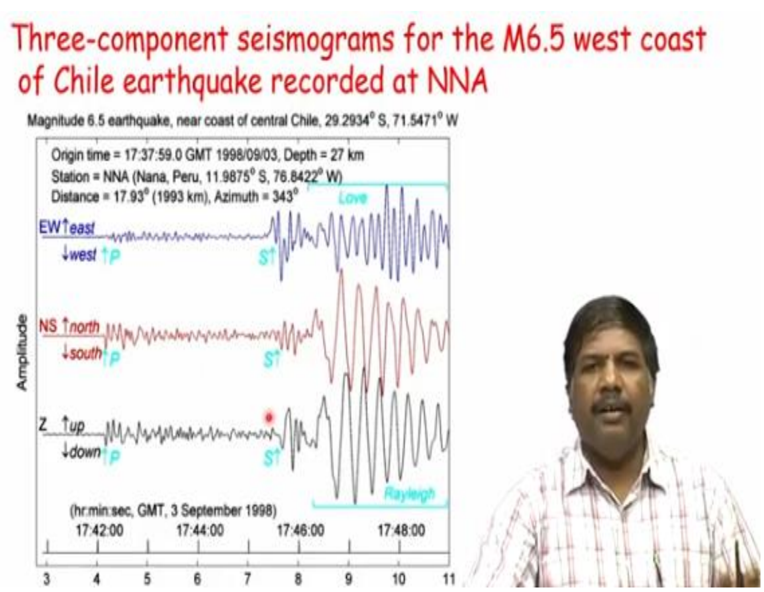

So this concept has been used to understand their seismic record, so where it occurs this is a typical earthquake you can see that here the P wave components are less, so here the P wave components are considerable here you much measure. So there are different P wave and S wave component and where it lays the S wave and Rayleigh wave where so this kind of record will give you the details of that.

So if you record this at a several places, you can try to understand the medium properties using this arrival time.

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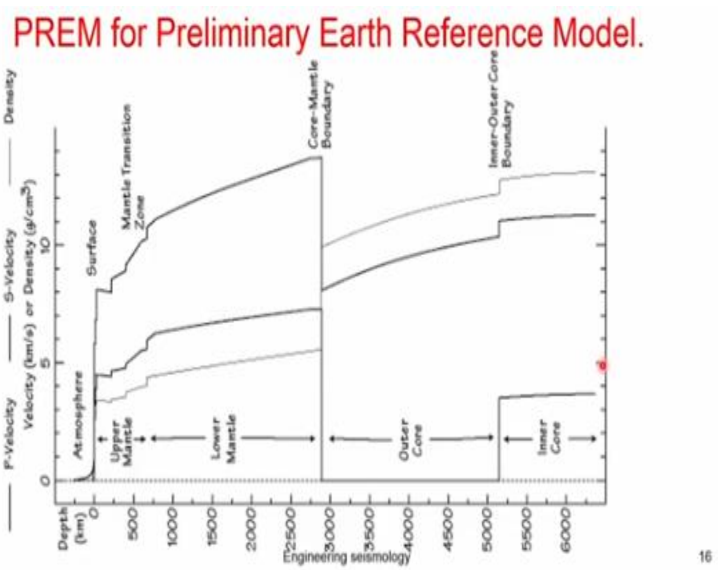

So that is like used to understand the earth interior and density. So you look at this plot this is actually the cross section of the earth. So which is the surface how the P wave, S wave and density varies with respect to depth. So it is atmosphere, the crust upper mantle, lower mantle outer core and inner core. You can see that outer core there is no S wave, because it is a liquid there is no S waves are taking place in the outer core and this is basically throughout if you cut a particular place you will not see the your S wave become a 0 at outer core then again it goes.

So this kind of measurement and the understanding help to develop here primary earth reference model. That means the entire earth system, the globe actually taken this kind of different level velocity.

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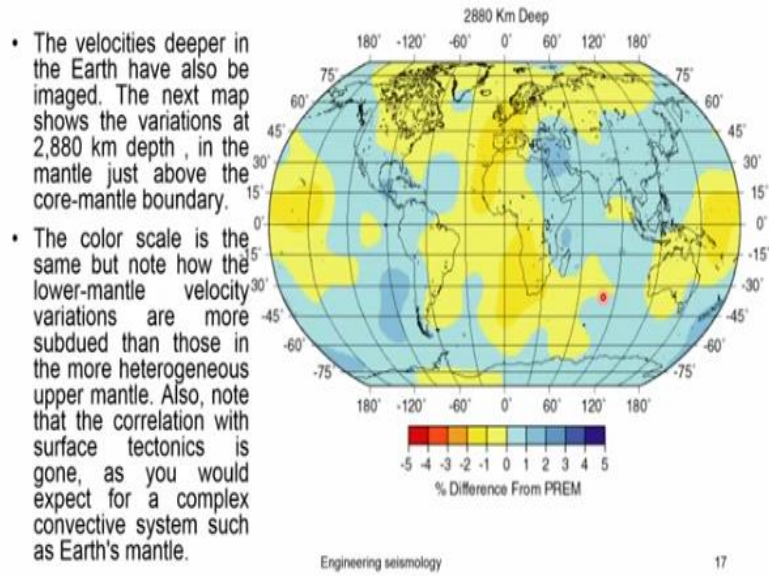

And try to understand how this velocities varies at a particular depth. So this is actually a typical difference of velocity at the 2880 kilometer deep from the surface. The surface you take it as a surface of the earth then from so many kilometer below you can see so you can see the material difference. So in particular places you can see two three the difference are large and some places the difference are negligible.

For example, here it is a uniform. Sri Lanka entire this same India also same but in between Sri Lanka and this one there is a joint here you can see that Australia you have the three type of this one, the difference is large even at a to a 200 kilometer deep. So this will give the, your interior of the earth and material present in the particular location. So this plays very important role in the deep geophysical exploration.

So people try to find out material present below the ground using this kind of survey. For example oil after 2 kilometer 3 kilometer, they found oil, they find the gold they find the coal, after 1 kilometer or 100 meter, 200 meter. So this kind of survey geo physical survey will help to basically get the minerals and then the subsurface contained in that they do extraction of that and then basically use it for the human application.

We have seen the gold was extracted from KGF. So, they found the gold, so by kind of exploration and then try to extract that. So not only gold there are several minerals like a diamond and all those in. So these deep geophysical surveys the another branch of steady people will involve on oil exploration, mineral exploration using the seismic waves. Whatever you are studied so far seismic and these are all the ways they use to interpret what type of material it is how the density varies.

How they nearby material and that material then they try to drill and take a sample and do analysis and find out the materials is worth the extraction. So iron ore, copper ore, the aluminum ore all those mining actually done after doing this kind of deep geophysical survey, using wave propagations or seismic waves what we study. So this is a place a very important role in the mining activity mineral exploration, all those things.

So in the seismology part also if you want to understand the earthquake location where the earthquakes are occurring if you want to understand the how far from your location to earthquake these wave propagation theories are very useful. So we can also see some animations where there are waves how it is generated. So you can see the seismic record.

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So this is a typical seismic record. So where you can see the type of waves you receive at a particular place. You can see here. So this is a seismic, so you can see the moment of the object even though the building was shown very big movement for the given event, but is source other seismogram record the this event. So you can see basically, see I just start once again to closely watch.

So we should thank this and you say this is the wave with created. So you can see the waves so where they are S wave, P wave travelled. S wave travelled and then the SS wave. So if we have the seismic station here, you can get all of them. So this seismic station as we are expected that it has a 3 component. So 3 component wave so each component you get a particular wave recorded.

So generally the vertical component P wave record very higher amplitude. So the two horizontal component, it does not record so much, that one then the other waves. So like the horizontal component will recorded well at the place where your horizontal direction the vertical component may not be recorded. You can see that how typically the object moves on you are amplitude.

So east, west, north, south how it behaves your object or how it behaves. So even though this one very high level of vibration, this is basically to understand how wave propagation it basically you see here P wave, S wave how it move. So such kind of moment is taking place in the any object due to the earthquake. So that is what you are trying to capture you can see this earthquake occurring now.

You can see the P wave travelling, S wave, surface wave this waves are moving towards you can see even it reaches to the object. So you lift the horizontal see then you get here recorded here. So then the other component this is a vertical component, two horizontal component, you get only the minor a disturbance then the S waves are coming now. It is going to hit the object you can see the S wave record on horizontal component dominantly.

You can see but the vertical component record it is only small amplitude, so similarly surface we are going to hit the object you can see the results are coming very close to the object going to hit you. So when you hit the object you can see how the object rolls basically see it rotates and also like a water waves it moves you can see the component. So basically the S wave and surface wave predominantly recorded in the horizontal component which is north, south and east, west and then the P wave prominently recorded in the vertical component of the seismometer.

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So this will help you to interpret what type of wave you recorded at a particular place, so this also useful to interpret here data. So now last 4 lecture we have been recapping the what we discussed in the different portion of the syllabus. So that this knowledge whatever we discuss will be useful for getting the prediction of the earthquake hazard, so that is why we are discussing these topics.

So we will continue this few more topics what we, the balance and followed by we will work on how you can use this knowledge or application site so that is the reason, so thank you very much for what watching this video we look forward so next class, so thank you.